MANAGING FATIGUE IN TRANSPORTATION: Promoting Safety and Productivity

Keynote Address by
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Because these Proceedings may be read by policy makers and others who have not been exposed to sleep knowledge, I thought a "side bar" which introduces or re-introduces a few basic definitions and conclusions would be helpful.

What is Sleep? There are many sleep behaviors which can be simulated in the waking state- - immobility, eye closure, snoring, to name a few. We should ask then, what is the fundamental difference between a human being awake and a human being asleep? Answer-- The crucial event that occurs as we fall asleep is an actively initiated shut down of our ability to see and hear the world around us. At one moment we are awake and can see, and a fraction of a second later, we are asleep and completely blind. Another way of saying this is that sleep is a behavioral state of complete perceptual disengagement from the environment.

Another fundamental fact is that sleep consists of two entirely different organismic states which are called REM sleep and non-REM sleep. These two states contrast markedly and alternate with one another in a basic sleep cycle throughout the night. The two chief characteristics of REM sleep, in addition to the occurrence of rapid eye movements, are (1) its association with dreaming and (2) its association with flaccid muscular paralysis, an inability to move any of the voluntary muscles except the diaphragm. When an entire night of sleep is considered, we typically see an orderly sequence of sleep stages defined by brain wave patterns with deep sleep occurring early and giving way to light sleep and longer REM periods later.

How much sleep do we need? Each of us, needs a certain amount of sleep each day on the average. If this amount is not obtained, a **sleep debt** is created. In other words, if the needed amount is not obtained habitually, the lost sleep accumulates progressively as a larger and larger sleep indebtedness. The average adult sleep requirement is a little over eight hours, and the great majority of individuals would fall within a range of plus or minus one hour. A powerful mechanism in the brain regulates the daily amount of sleep by progressively increasing the tendency to feel drowsy and to fall asleep in direct proportion to the size of the sleep debt. This process ensures that most people will average the amount of sleep they need, or close to it, over time.

What causes us to get sleepy? Prior sleep loss determines the strength of the tendency or ability to fall asleep. If your sleep debt is zero, sleep is impossible. If the sleep debt is very low, a very small amount of stimulation can keep us awake. If the sleep debt is very large, no amount of stimulation can keep us awake. It should be clear that all of the things we say cause us to become drowsy or to fall asleep actually are not causal. A reduction of stimulation only unmasks the tendency to fall asleep that is already present. To say that boredom causes sleep is wrong. If boredom is quickly followed by drowsiness, we are carrying a large sleep debt and we need stimulation to avoid falling asleep.

America is a sleepy society. How many Americans are seriously or dangerously sleep deprived? There is no doubt whatsoever that vast numbers of us in school, in the workplace, in the transportation industry, in a variety of service industries, and particularly, in shift work situations, are carrying a dangerously large sleep debt.

In one of the best scientific studies, investigators studied several hundred people who said they had no problem with daytime drowsiness. Using a precise measurement of sleep tendency, they found that 25% of the test population was dangerously sleepy. We have studied smaller samples at Stanford, for example, students and nurses, and have found that the percentage who are dangerously sleepy can be as high as 80%. By dangerously sleep deprived, we mean, of course, a dangerously high risk for some sort of accident involving inattention or unintended sleep. In all walks of life, it is likely that sleep deprivation has consequences: diminished productivity, mistakes, irritability, fatigue. For most people, the accumulation of a serious sleep debt appears to have been so gradual that they attribute negative consequences to many other things and so do their doctors.

What is the Biological Clock ? What does it do for us? The biological clock is a term applied to the brain process which drives our daily rhythms in body temperature, hormone secretion, and a host of other bodily activities. Its most important function is to foster the orderly alteration of sleep and wakefulness. An important scientific breakthrough was the discovery of the precise location of the biological clock. It is housed in two tiny bilateral areas of the brain called the suprachiasmatic nuclei. Its major role in terms of sleep and wakefulness is to provide an internal and very powerful wake-up signal to the rest of the brain. This is the clock-dependent alerting that powerfully opposes the tendency to fall asleep and in the absence of other stimulation is sufficient to keep us awake all day if our sleep debt is relatively low. In the ordinary 24-hour environment, clock-dependent alerting is generally synchronized with the daytime, but if we travel rapidly to other time zones, it is not, and we experience "jet lag."

What are sleep disorders? Sleep disorders are illnesses and disturbances of sleep and wakefulness that are caused by abnormalities existing only during sleep, or abnormalities of specific sleep mechanisms. These abnormalities frequently produce symptoms that are recognizable during wakefulness, but the fundamental pathology exists during sleep. Though the symptoms that exist during wakefulness can be helpful in recognizing the possible existence of a sleep disorder, an absolute certainty requires an examination of the patient during sleep, widely known as a sleep test, or polysomnography.

Which sleep disorders are commonly associated with excessive sleepiness? Any sleep disorder which is associated with a reduction or fragmentation of sleep has the potential to cause the victim to be excessively sleepy in the daytime, or if a shiftworker, whenever the major wake period occurs. The disorders which are most typically associated with severe fatigue while awake are obstructive sleep apnea and narcolepsy. Others include the chronic insomnias, Restless Legs Syndrome, periodic leg movement, and biological rhythm disorders.

How common are these sleep disorders? Very much more common than anyone knows is the best answer to this question. The national prevalence has been established for one specific disorder, *obstructive sleep apnea*, at 24% of adult males and 9% of adult females. Separate studies in elderly populations and non-adults allow us to conclude that 30 million Americans are victims of this sleep disorder across the full range of severity.

What is obstructive sleep apnea? Sleep apnea is a disorder whose victims cannot breathe when they fall asleep. The word *apnea,* refers to the absence of breathing. The failure to breathe is caused by the collapse of the tissues of the throat producing closure of the airway. Once this has occurred, the victim may continue to make respiratory efforts without airflow. Blood oxygen drops and finally triggers an alarm response so that the victim wakes up to breathe. In a severe condition, this occurs hundreds of times as the sleep deprived victim immediately returns to sleep. In the morning, these hundreds of awakenings are completely forgotten. If the sleep apnea condition has progressed to a level of severity, it is almost always associated with cardiovascular disease. Victims have high blood pressure, which is difficult to control, and are likely to have already had heart attacks or strokes. It also causes severe cardiac arrhythmias during sleep and these arrythmias can be fatal. In addition, severe obstructive sleep apnea causes overwhelming daytime fatigue. This occurs because the victims must wake up hundreds of times to breathe and therefore sleep looses its restorative power. The condition is frequently misdiagnosed as chronic fatigue syndrome, or hyperthyroidism, or depression. The cardinal symptom of the disorder is loud snoring.

Drowsiness is a Red Alert! Vast numbers of us are suffering from a sleep disorder or sleep deprivation or both. The final, common path of impairment and danger is sleepiness. In the sedentary highway, rail, air situations, we progress toward serious impairment. Our eyelids get heavy, our heads sag, we feel that wave of strong drowsiness. All hard driving, sleep deprived readers should take this admonition very seriously. **Drowsiness is red alert!** Drowsiness is the last step before sleep, not the first. Drowsiness means you are at the abyss. I believe that if we all would respond to the first wave of drowsiness as an alarm-- as an emergency requiring an instantaneous response-- huge numbers of human tragedies, suffering, and catastrophic events would be avoided.

And lastly - The area of fatigue and transportation cries out for additional research to assess the precise magnitude of the problem and to perfect effective countermeasures. In addition, there must be a cultural change in which corporate, federal, and regulatory leadership make fatigue a major priority and hold individuals and institutions accountable.

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After editing the transcript of my remarks for these "Proceedings," I was a little uneasy that they did not get right to the point with regard to a number of key issues. Anyone who is not intersted in "historical background" and after dinner anecdotes should skip the next few pages.

Thank you all very much. As the "After Dinner Speaker," I at least have the advantage of being able to comment on some of the events of the day. First on my list is to acknowledge the stunning success of this meeting. I believe that nearly 600 of the 1000 individuals and organizations invited are here from all over the United States. This is surely some kind of record, but more important, it validates the theme of the meeting, its importance, and its timeliness. All of the organizers deserve high praise. Of the many, I will single out Mark Rosekind and Julie Beal for their key roles. I also want to acknowledge the leadership and vision of Chairman Jim Hall. His remarks this morning were truly inspiring. Speaking as one of the so-called "pioneers" of sleep research, it is a thrill to be here, and the purpose is surely a meaningful culmination and validation for the many laboratory and operational investigators who have worked so hard on the problem of fatigue and transportation safety. Finally, I wonder if Board member Hammerschmidt knows that there is an Arkansas Sleep Society. I can assure him of its existence. I was at the founding meeting.

This is a very appropriate occasion to announce a recent landmark event. In the Senate Transportation Appropriations Bill, there was a line item, a small incremental appropriation for the National Highway Traffic Safety Administration to support a "driver fatigue initiative." The House version of the Transportation Appropriations Bill did not include this item. However, with the support of Representative Frank Wolf, Chairman of the House Appropriations Transportation Subcommittee, the Conference Report which just came out included this funding in the full amount. The initiative is highly specific in addressing fatigue and its consequences on our highways, and it is intended to be continued in subsequent years. You all applauded one of our Congressional guests, Stephanie Gupta, earlier in the day. She certainly deserved the applause because she is the accountable staff member. We must also recognize the leadership of Senator Mark Hatfield and his staff who thoroughly understand the problem of fatigue and its consequences, and who originally introduced the legislation.

I think part of the reason this meeting is so successful, and part of what brought you all here, aside from, of course, the imprimature, the prestige and scientific integrity of the National Transportation Safety Board and the National Aeronautics and Space Administration, is the clear understanding that our purpose is to tackle the problem of fatigue. We are no longer debating if it is a serious problem. That is behind us. We are here to do something about it.

I might just say a few words about how I got started in sleep research. Earlier in the day, one of the speakers, Dr. Charles Czeisler, mentioned Professor Nathaniel Kleitman. At the time, I wondered how many of you had heard of Professor Kleitman, and were aware of his accomplishments. In addition to his body of research on sleep, he was my teacher at the University of Chicago. Since he was the only man in America who was studying human sleep when I chose to attend medical school at the University of Chicago, had I made any other choice I would surely have had a very different career. We discovered and described rapid

eye movements during sleep in the early 1950's in Kleitman's laboratory. The nature and function of REM sleep and its relation to dreaming dominated my efforts for at least a decade. My involvement with sleep deprivation was limited to staying up all night in the sleep laboratory, and then falling asleep in class the next day. I was thrown out of several classes by professors who did not understand fatigue any more than many individuals in our society today.

What we didn't know scientifically about sleep deprivation and its role in many aspects of our society in the 1950's would fill a book. In 1958, I was involved in a highly visible wakefulness marathon. A disc jockey was staying awake for 200 hours in a glass booth in Times Square in New York, and claiming he was breaking the world's record for longest duration without sleep. Several investigators from the University of Oklahoma were observing him and carrying out a variety of performance tests. I was, at the time, working in New York. I had developed the technique of continuous all night polysomnography, and I had defined the EEG stages of sleep which allowed them to be quantitatively measured. My task was to record the disc jockey's recovery sleep when the marathon ended. This single recording conclusively revealed the existence of what is now called REM rebound.

Thirty-eight years ago nothing much was known about the psychotrophic effect of stimulants. In order to stay awake, the disc jockey took progressively higher doses of methylphenidate (Ritalin). On the last day of the marathon, I believe the dose was up to 300 milligrams. This precipitated a psychotic episode (fortunately very short lasting), but the episode was mistakenly attributed to the sleep loss by the investigators. This seemed to confirm stories from the Korean War about sleep deprivation as a form of coercion and its psychological effects, as well as some speculations about the psychological role of the newly discovered organismic state of REM sleep. For my own part, I was diverted for a time from a direct interest in total sleep deprivation by this event and subsequent studies.

Randy Gardner was also mentioned today. He was a high school student who in stayed awake for 240 hours in 1965. His motivation was to establish a new world's record for going without sleep. I was intimately involved in this event, leading a team which carried out observations both during the deprivation period and during the recovery. We were still very naive, and we allowed him to "rest his eyes" much more than we should have. Accordingly, knowing a great deal more today about the occurrence of microsleeps in apparently awake individuals, I'm not so sure Randy Gardner was undergoing total sleep deprivation. However, he did endure an enormous amount of sleep loss, and came through the ordeal with relative ease. We mistakenly thought he was adequately recovered after one sleep period, so that was all we recorded. We now know that it takes longer to repay lost sleep.

Another high school student who lived near Stanford University where I became a member of the faculty in 1963, decided he was going to break Randy Gardner's record by staying awake longer than 240 hours. I was happy to conduct observations as I had done with Mr. Gardner. However, to my great surprise, within two days he "fell off the cliff," to use the expression coined by Dave Dinges in his presentation earlier today. After about 60 hours of wakefulness, the student was crying, sobbing, and begging to be able to go to sleep. There must be huge individual differences in response

to sleep loss which we know almost nothing about.

In 1964, my family and a few friends were having a little picnic dinner in our back yard. We were extremely startled when a car came crashing through the bushes and into our back yard, stopping about 10 feet from where we sat with our guests. The driver, fortunately unhurt, was a Stanford student who was quite drunk and had missed the turn. In those days, they had a student court. I attended the trial, and was furious when the only punishment was a mild reprimand. That's when I learned that our society didn't seem to care very much about drunk driving. But thanks largely to Mothers Against Drunk Drivers (MADD), you have seen an enormous cultural shift in attitude about DUI. It is no longer acceptable.

Shortly thereafter, I served for the first time as an expert witness in a lawsuit involving responsibility for damages as the result of a sleep-related crash. At the trial I was asked the question, "Is someone who falls asleep at the wheel truly responsible?" Amazingly, it was the first time I ever considered that question and it has preoccupied me and my research for the ensuing three decades. In this instance, a driver had unambiguously fallen asleep, and as a result, four people had died. As the driver approached the moment of sleep, was there a point where he was helpless, and could not do anything even if he wanted to? Or, was he simply irresponsible and at fault for deliberately letting it happen?

From 1970 to about 1985 I was enormously preoccupied with getting sleep disorders medicine fully operational, and in establishing the American Sleep Disorders Association. A major landmark for me occurred in 1982 when I became involved in an international project to study the adequacy of layover sleep of pilots following transoceanic flights ponsored by NASA/Ames (ref). The project was led by Dr. John Lauber who went on to become a member of the National Transportation Safety Board for two terms. His key role on the Board was praised today, and I will join in. John was a wonderful colleague, and from him I learned an enormous amount about the operational community.

In 1988, while I was still Chairman of the Association of Professional Sleep Societies and I asked John to be the keynote speaker at our annual meeting. I hope some of you remember his outstanding presentation about fatigue in transportation. He showed a videotape of the China Airline near disaster, where a Boeing 747 was flying at 41,000 feet, and because of a pilot error, tail spinned all the way down to 9,000 feet. The computer simulation of this "incident" was just about as riveting and suspenseful as anything you could possibly imagine.

John really inspired me. So much so that a few weeks later in Washington, DC, Mr. Dale Dirks, Washington representative of the American Sleep Disorders Association, and I persuaded Senator Ted Kennedy, Chair of the Labor and Human Resources Committee, to create the National Commission on Sleep Disorders Research as part of the NIH Reauthorization Act. The delay and jockeying to appoint Commissioners was an unexcelled example of our creaking bureaucracy. By the time the Commission had it's first meeting at the end of March two years later, where I was elected Chairman, serious efforts to balance the Federal budget were well underway.

I knew several members of the AIDS Commission, and I knew that they had been supported by an annual budget of $2 million and a dedicated support staff of ten people. You can therefore imagine how I felt when the Director of NIH came to the first Commission meeting and announced there were no funds. As far as I know, this was the first of what have come to be called "unfunded mandates." It was also a personal moment of truth. On the one hand, it was obviously the opportunity of a lifetime to bring societal issues related to sleep deprivation and sleep disorders onto the front burner. On the other hand, how could the Commission possibly function with no financial support?

I decided finally that I had to do whatever was necessary to take advantage of the opportunity. Fortunately, several individuals from the private sector provided partial funding which enabled us to carry on. One of these was Dr. David Hamburg, President of the Carnegie Corporation, who is one of the men I admire the most on this planet, and has devoted his life to saving it.

When the Commission finally began to operate, the very first Federal document that we received was the NTSB report of the 1989 grounding of the Exxon Valdez. It was a dramatic and compelling example of the catastrophic consequences of fatigue. It was just what we needed to galvanize our work. We also received all the other reports that were mentioned this morning by Jim Danaher, the railroad accidents, the fatal-to-the-driver truck accidents, and the World Prodigy grounding. The early and continuous hook-up with NTSB was extraordinarily important in our work.

At the end of the Commission's task, we had learned and we reported to the Congress that society is plagued by two gigantic, but largely hidden, problems. The first is the existence of pervasive sleep deprivation in all components of society. The second is the pandemic of undiagnosed and untreated or misdiagnosed and mistreated sleep disorders. Realize if you will, that we knew this in 1991. Of the latter, the most prevalent, as you've heard today, is obstructive sleep apnea. It is also the most serious of the highly prevalent sleep disorders, and as you now know can cause overwhelming fatigue.

Once again, I want to acknowledge the very strong support we have received from the Senior Senator for the State of Oregon, the Honorable Mark Hatfield. In 1990, the Commission was invited to hold a public hearing in Portland and we captured his attention on that occasion. He has been a staunch advocate ever since. He is now Chairman of the Senate Appropriations Committee. When the Commission recommended a Federal focus to deal with the problems of fatigue and sleep disorders, Senator Hatfield introduced the legislation to create the National Center on Sleep Disorders Research. This legislation was later folded into the NIH Reauthorization Bill and signed into law by President Clinton on June 10, 1993. I was very excited because I thought this would be an opportunity to have my picture taken in the White House when the President signed the NIH Reauthorization Bill. I had an acquaintence on the President's staff so I was pretty sure I could get an invitation. This is when I learned things were not optimally organized because nobody knew when the signing ceremony was going to happen. Nobody could tell me. I was supposed to go to Paris for a conference, and I held off as long as I could. Finally I got on the plane, and when we landed, I learned that the signing ceremony was taking place that very day. I was sad, even in Paris.

There was a little amusing byplay surrounding passage of the Bill to create the National Center. In his remarks on the floor, Senator Hatfield opened with a dramatic description of an event in his home state of Oregon where a truck driver had fallen asleep and "wiped out a town." It was, of course, a very small town, but at 5:00 A.M. a heavy truck didn't follow the gentle turn of the highway and without turning or braking smashed through the filling station, the grocery store, and came to rest in the tavern. A controversy erupted in the Oregon newspapers because the driver, who was not fatally injured, denied that he had fallen asleep or had been suffering from fatigue. So here was a Senator on one side, and the truck driver on the other. There are now guidelines promulgated by NTSB to deal with this type of accident. I wish we'd had a firm grip on them when this happened, so we could have supported the Senator.

I have already said that this meeting is truly a landmark. Because of that, I decided to spend the day listening very carefully to the speakers and to underscore some of their most important points. I've been teaching undergraduates at Stanford since 1963, and I'm always amazed at what they do not remember from my course. When you encounter a student, a year or so later you're lucky if they remember two or three things. I'm sure you'll do much, much better than that. But even so, there are some things we hope you will remember and take seriously for the rest of your life.

Here is the first point I want to make very firm and clear. Fatigue is the feeling that accompanies a strong physiological tendency to fall asleep. Most people think it takes a lot of time to fall asleep, but it doesn't. The actual transition from wake to sleep is virtually instantaneous. Drowsiness is not the first step in the process, it's the last step. It is the last event of wakefulness just as we are actually falling asleep.

In 1977, we published a study (ref) that documented the rapid and abrupt nature of the transition from awake to sleep and vice versa. In this study, subjects lying supine with continuos brain wave recordings and with their eyelids taped open were exposed to the brilliant flash of a strobe light situated about six inches above their face. Their task was to press a micro-switch taped to a finger when they saw the flash. The strobe light was programmed to flash irregularly every two to eight seconds. In a typical sequence, the subject would execute a number of responses immediately after each flash of the strobe light. Then, abruptly, we would see a failure to respond. If we immediately asked the subject why he didn't press the micro-switch, he would invariably say, "The light didn't flash." In other words, he did not press the switch in response to a blinding flash that occurred right in front of his open eyes because he didn't see it! He was completely, functionally blind, whereas several seconds earlier, he saw the flash perfectly well. When we examine the brain wave patterns associated with this response failure, we almost always see a brief (one to several seconds) microsleep. At the moment of sleep, a virtually instantaneous transition, the subject has become completely blind. Subjects usually report a strong wave of drowsiness just before falling asleep. We have done a number of experiments along these lines and it is well established that human beings can progress from wide awake to sleep in literally seconds, maybe even faster. We may conclude that when we feel a strong wave of drowsiness while operating a vehicle, if we do not respond to it immediately, we have placed ourselves and others in extreme jeopardy.

You heard about the Multiple Sleep Latency Test (MSLT) several times during the day. I asked at least 15 people attending this meeting if they were familiar with this procedure. All said no. The MSLT is a standardized method used all over the world for the objective measurement of daytime sleepiness. It has been a very powerful tool in understanding human sleep deprivation, but its great usefulness is inversely proportional to the awareness of it in the transportation industry.

This direct scientific attack on daytime sleepiness would not have come about were it not for the clinical problems we were seeing on a daily basis in the Stanford University Sleep Disorders Clinic, of which I was then Director. Our initial interest was in patients diagnosed as having *narcolepsy*, an illness typified by irresistible attacks of sleep, and in those diagnosed with *obstructive sleep apnea,* a condition of severely disturbed respiration during sleep. Both of these conditions drastically impair daytime alertness. However, when we first began studying these patients, we had no objective way to measure sleepiness.

During the spring of 1976, a group of Stanford students carried out the first MSLT type study of daytime alertness under conditions of total sleep loss. This experiment helped set the ground rules of what would become the standardized form of the test. The students stayed awake for two days, during which time a "sleep latency" measurement was taken every two hours as follows: The student was told to lie quietly in bed, in a darkened room, and to try to fall asleep. As soon as the subject fell asleep, the test was ended—that is, the student was roused—and "sleep latency" was scored according to how many minutes had elapsed (a score of 0 indicating maximum sleepiness; a score of 20 maximum alertness). If the student failed to fall asleep within twenty minutes, the test was ended and the student scored 20. With this test design, no sleep time was permitted to accumulate during the experiment, and the subject did not get too bored if unable to fall asleep. (Sleep latency was also measured before the experiment and again after the subject was finally permitted to sleep.)

When Mary Carskadon and I, with our undergraduate technicians, launched the Stanford Summer Sleep Camp, we continued these methods. During ten remarkable summers, we studied sleep patterns and daytime alertness in people of all ages, who spent anywhere from several days to several weeks at the "camp." In one early study, Stanford University undergraduate volunteers, given the MSLT on each of several consecutive days, were found to be pathologically sleepy (their sleep latencies were below five minutes) even though they were spending their "normal" eight hours in bed. When their time in bed was extended to ten hours (with about 9 1/2 hours of actual sleep), their daytime alertness progressively improved. The cause of the severe sleepiness in the undergraduates was obvious: *They were simply not getting enough sleep.* Meanwhile, we were finding that 10-,11-,and 12-year-old children who routinely spent ten hours in bed at night had optimal physiological and subjective alertness in the daytime.

Some people think you can **learn** to fall asleep quickly even if you are not sleep deprived. This is wrong. Children who are prepubertal, the 10, 11 and 12 year olds, sleep 9 1/2 to 10 hours at night and they are not the least bit sleepy all day long. Nothing can cause them to fall asleep. Boredom ? No. Warm room? No. Heavy meal? No. None of these things decreases the daytime alertness of children who have no sleep debt at all.

In what I regard as our most important sleep camp study, we partially sleep-deprived ten young adults for seven consecutive nights, allowing them just five hours sleep per night. Over the seven-day period, with the same amount of sleep each night, their daytime alertness progressively *worsened*—a result that has been confirmed numerous times by other investigators. This was the first study strongly suggesting that all lost sleep accumulates as a debt.

The issue and concept of sleep debt came up many times today. Sleep debt is real. It's been elusive in the past, but today I think the scientific evidence for its existence is incontrovertible. In other words, there is a "sleep debt" that accumulates just like any credit account. The brain keeps very accurate figures on the accruing sleep deficit, which drives the tendency of the brain to fall asleep. My first use of the term, however, was in testimony to the House Appropriations Committee. I was trying to shock them into paying some attention by saying that the National sleep debt was more serious than the monetary debt. I had a poster that I showed with the sleep debt mounting up to ever more dangerous levels.

Several groups of investigators, using the MSLT, have found severe physiological sleepiness to be pervasive in communities and in workplace environments. You might expect more people to complain of general fatigue. But people have a strange inability to perceive their sleepiness accurately. Dr. Thomas Roth and his colleagues at Henry Ford Hospital Sleep Disorders Center (one of the most outstanding) in Detroit reported in 1988 on a study of a large sample of young adults. The subjects were recruited specifically because of their claims that they were *not* bothered by daytime sleepiness or any other health problem. Yet when their daytime alertness was evaluated after eight hours in bed, *34 percent tested pathologically sleepy!* Only about 10 percent of those who claimed to be feeling fine were in fact optimally alert. Almost certainly, if we studied only individuals who actually *admitted* to experiencing daytime sleepiness, a much higher percentage would exhibit sleepiness at the pathological level.

While sleep/wake issues affect myriad public-policy areas, there is an unfortunate tendency for uninformed policy makers to suggest that it is "normal" to be sleepy. To test this, Dr. Roth and his colleagues selected a group of their sleepiest subjects and persuaded them to spend ten hours in bed for six consecutive nights. Just as we had found in the Stanford Summer Sleep Camp, ten hours of sleep improved their daytime alertness significantly. Furthermore, their cognitive performance also improved! Thus, the intellectual capacity of these sleepy individuals, was significantly impaired. If feeling this way is the "norm," then we are unquestionably a sleep-deprived and sub-optimal society. Nearly all of us need more sleep than we get.

Every hour of sleep less than his or her needed amount is carefully registered by the brain as a debt, and this debt is precisely tabulated over time. It is quite possible that the debt includes an hour lost a month ago or a week ago as well as last night. Obviously, this assumes that there is a specific amount of nightly sleep for each individual which will maintain the same degree of daytime physiological alertness over time. It also assumes that this amount varies somewhat from individual to individual.

In an individual who needs nine hours a night, and who sleeps six hours a night for a week, the lost sleep would add up to a debt of 21 hours

by the end of the week. This sleep debt drives the tendency of the brain to fall asleep, and the amount of the debt, **not** the feeling of sleepiness, determines the level of risk that any person operating hazardous equipment or making crucial decisions may make a disastrous error. Persons who are very sleepy in the daytime even though they are sleeping around eight hours at night and do not have a specific sleep disorder can reduce the problem by increasing their daily amount of sleep. This is usually done by increasing the time in bed.

Two similar experiments done more than twenty years apart dramatically confirm the concept that human beings can unknowingly carry a large sleep debt. Neither experiment was designed by the researchers primarily to study sleep. In both experiments, brain waves were recorded continuously as one of many measurements of the effects of the experimental protocol on the human volunteers.

The first experiment was carried out over twenty-five years ago at the U.S. Naval Hospital in Bethesda, Maryland, as a test of sensory deprivation. At that time, it was hypothesized that a substantial reduction of sensory input would dramatically impair normal mental processes, and that disorientation, hallucinations, and even psychosis, might be the consequence. Subjects were required to remain in a cubicle, where they were isolated from light, sound, and interactions with the outside world. The temperature was held constant, neither perceptibly cool, nor perceptively warm, and the subjects wore gloves to minimize tactile sensations. Brain's waves were recorded continuously 24 hours a day by means of very thin wires that were looped through the subjects scalp so they did not have to be replaced. Subjects remained in this sensory deprivation situation for one week.

Having absolutely nothing to do, subjects generally slept a great deal throughout the first twenty four hour period. The mean total sleep time for the group was above 16 hours on the first day. However, the mean total sleep time declined on each successive day, and on the last (seventh) 24 hour period, the group mean was close to eight hours.

This experiment might be viewed as a test of the old theory that sensory bombardment of the brain was necessary to maintain wakefulness. If so, it would be an extremely negative result, because with a tremendous reduction in sensory input, sleep time did not remain high. The subjects in this experiment were young naval personnel. Since we now believe that nearly all young people are chronically sleep deprived, it may be assumed that even if the subjects had maintained reasonably normal schedules prior to the experiment, they would have begun the sensory deprivation protocol carrying a substantial sleep debt. We may assume that this sleep debt powered an enormous increase in total sleep time when there was essentially nothing else to do all day long. However, as the sleep debt was progressively reduced, the sleep drive progressively weakened and the daily amount of sleep decreased accordingly. Even with absolutely nothing else to do all day long, the subjects were unable to sleep more than eight hours.

The second experiment, also mentioned today by one of the presenters, was carried out by Dr. Thomas Wehr and his colleagues at the National Institutes of Health. Its purpose was to examine the effect of different photo periods (duration of time spent in the light, as opposed to in the dark) on human mood and function. The experiment was carried out in a laboratory setting with continuous recording of sleep parameters while subjects were in bed in the

dark. Each subject slept in the laboratory 24 hours a day, seven days a week for five consecutive weeks.

During the first seven days, the photo period during which subjects were out of bed in the light was the conventional 16 hours, and each day they spent the same eight hours in bed in the dark. After one week, the photo period was changed to ten hours during which the subject were out of bed in the light; and they were required to be in bed, in the dark, for the same fourteen hours each day over the course of 28 consecutive days. During the five week period, the subjects were administered daily mood scales and a variety of other tests.

During the first week, or baseline period, the mean nightly sleep time for the subjects was 7.6 hours. When the subjects were switched to the ten hour photo period followed by fourteen hours in bed, in the dark, their total sleep times jumped to nightly amounts above twelve hours on the first day and then gradually declined. In the fourth week of the ten hour photo period schedule, total sleep time for the group had leveled off to about eight hours and fifteen minutes each day even though the opportunity to sleep remained at fourteen hours.

The interpretation of these results is that the subjects entered the protocol carrying large individual sleep debts. Of course, neither the subjects nor the researchers were aware of such a possibility. The baseline period certainly did little to reduce the subjects' sleep debts, and may even have resulted in a small increase. When the opportunity to sleep was greatly increased, the large sleep debt, in the same manner as in the first experiment, powered a very large increase in total daily sleep time. As the sleep debt decreased, total sleep time per day declined proportionally. If we assume that the "steady state" value in the last week of the ten hour photo period represented the actual daily sleep need for this group of subjects, we may conclude that all daily amounts above these values represented "extra" or "make-up" sleep. Accordingly, the mean reduction or "pay back" of the sleep debt averaged about thirty hours. If subjects were not at all sleep deprived, they would have to spend more than three consecutive days with no sleep at all to accumulate a sleep debt of similar magnitude. Another very notable result of this experiment was the dramatic improvement in the subjects' mood, sense of well being, and energy level as indicated by various tests.

These experiments demonstrate that individuals who are getting what society would deem to be normal amounts of sleep, can, at the same time, be carrying a large accumulated sleep indebtedness. How long such an indebtedness would persist if no extra sleep were obtained is not known. However, it is obvious from the second experiment that to be able to sleep thirty extra hours, and to have accumulated such a debt in small increments means that sleep indebtedness must persist for substantial amounts of time-- weeks or months at the very least. In addition, this experiment, and others like it, present evidence that a large sleep debt impairs our mood, our sense of well being, our energy, and our intellectual function. This means that the negative consequences of chronic sleep deprivation are not confined to having microsleeps at critical moments. There is also a general and unrecognized global impairment. Finally, it is reasonable to hypothesize that a major improvement in our function could be achieved by reducing our sleep indebtedness to a very low level.

All we hear about today is balancing the budget and cutting all sorts of government programs. However, in my opinion, it is the "National Sleep Debt" that we should be worried about, and the newly Republican Congress should have an equal fervor for doing something about this problem. In 1995, there was a dramatic footnote to "America's largest oil spill," the aforementioned grounding of the giant tanker, Exxon Valdez. In civil trial, the jury awarded the plaintiffs five billion dollars in damages. Thus, a single sleepy person cost his company in excess of seven billion dollars, together with an untold loss of goodwill. And companies still have not taken this problem seriously on a large scale.

The pervasivness of sleep deprivation is even more clear today than it was during the 1990-91 study of the National Commission on Sleep Disorders Research. Moreover, we are sure that crashes caused by falling asleep at the wheel are vastly underreported. Many states do not even have a category for "fatigue" as a cause of an accident. Accordingly, we have the grotesque situation that there is no cause of death when people fall asleep at the wheel.

An accident occurred recently, practically in my back yard, which dramatically emphasized the inadequacy of investigation and reporting. A two lane highway runs by my house. It is straight for a long distance and then there is a gentle curve. Recently, a car traveling approximately 50-60 mph according to witnesses, approached the curve and without braking or changing direction drove straight into a tree. Hearing the ambulance and police car so near by, I ran to the scene to see what had happened. The driver was dead and he was subsequently found to be free of drugs or alcohol. He looked to be about 30 years old making a heart attack highly unlikely. I asked the investigating officer if he was going to try to find out how long the victim had been driving prior to the accident, or perhaps ask a family member about his schedule during the previous week, and whether or not he was a loud snorer. At a certain point, the investigating officer became irritated with me and asked me to leave him alone while at the same time suggestively patting his handcuffs. The next day in the paper, he was quoted as saying, "The car had veered off the road and the cause of the accident was unknown." This is actually exactly the type of accident where the National Transportation Safety Board would follow up with an investigation of the victim's schedule, and, if appropriate, would identify fatigue as the cause.

Now, you immediately ask the question, "Why aren't we aware of these huge loads we are carrying?" The main reason is another process that has also been mentioned today, the circadian process, which causes a period of strong alertness at the same time each day. When the Multiple Sleep Latency Test is extended into the evening hours we always see a marked improvement in alertness, or a lengthening of sleep latency, with no sleep at all. This is what we at Stanford call "clock dependent alerting." There is a miss attribution of this process particularly by young people who experience this alerting in the evening, that yes, I'm fatigued, I'm tired, I'm sleepy, but the fatigue disappears. It dissipates. It goes away. I feel great in the evening. If any of you teach undergraduates and are involved with them, you know they are vivacious and energetic in the evening even though they were groggy and falling asleep in class in the day time. But they don't understand that when this alerting affect passes, they are even more vulnerable to the likelihood of falling asleep. This is when they are driving home from parties and other evening activities.

Another point to emphasize was discussed by Dr. Roth today. I think it is one of the most important findings in this whole area. Sleep deprivation dramatically potentates the sedative effect of alcohol. I just talked with Pat Waller, the Director of the University of Michigan Transportation Research Institute. She said that one of their big research issues is the very low alcohol levels in the blood of young people who have had fatal accidents. They feel such low levels should not be causing accidents. However, the real culprit in many crashes "caused" by alcohol is sleep deprivation.

The possibility was raised today that people who work in hazardous situations should be screened for obstructive sleep apnea. The National Commission carried out a study of truck drivers. We found a shockingly high prevalence of sleep apnea in overnight tests (ref). We also found several drivers who were severely ill. One driver kept falling asleep on the chair while we were trying to hook him up. We were allowed to send him a letter. In retrospect, I was ashamed that I'd walked away from that.

Now, we're here in Tysons Corners to do something, and I think a very important part of this meeting will be tomorrow. I wanted to just make a few suggestions. We must assume fatigue in all accidents. We must investigate all accidents using the NTSB guidelines. In a recent accident that occurred in White Plains, New York, a propane truck drifted out of its lane, crashed into the concrete support of an overpass, and exploded. It was a horrible accident. The driver was killed instantly. Headlines the next day in the New York Times read "alcohol and drugs didn't cause the crash, what did?" So apparently the authorities, or at least the journalists who were there, were clueless about the facts of fatigue and its role in crashes.

The effort to enhance awareness about fatigue and sleep disorders should be totally cooperative. Such efforts could be enormously multiplied with the participation of all of the operational communities at this meeting. We should ask not just our companies and our industries, but our entire communities, "Are we educating everyone about fatigue?" Is this knowledge going to grade school children and truck drivers? Is it going to middle school children and airline pilots? Above all, is it going to high school students and others who are learning to drive? Are any of the state colleges teaching this material? What about graduate programs? How can we tolerate the absence of teaching about sleep deprivation and sleep disorders in our medical schools? I say to you today, this group is an island of awareness in a vast sea of ignorance. "American society," to quote Senator Hatfield, "is a vast reservoir of ignorance." You can fill the reservoir with knowledge. You can make a difference.